

The HEM-3 User's Guide

HEM-3 Human Exposure Model
Version 1.0.0 beta

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1. Introduction

The Human Exposure Model-3 (HEM-3), Version 1.0.0 provides a streamlined, but at the same time rigorous tool for estimating ambient concentrations, human exposures and health risks that may result from air pollution emissions from a complex industrial facility, or a cluster of facilities located near one another. HEM-3 is designed to be used by EPA, states, local agencies, industry, and other stakeholders.

1.1 Organization of the HEM-3 User's Guide

This User's Guide is organized into seven chapters:

Chapter 1	Provides a brief introduction to HEM-3, including the main features and requirements of the model.
Chapter 2	Provides instructions for installing HEM-3.
Chapter 3	Provides instructions for preparing the input data needed by HEM-3 and running the model.
Chapter 4	Describes the calculations performed by HEM-3.
Chapter 5	Describes the outputs produced by HEM-3.
Chapter 6	Describes the data libraries used by HEM-3.
Chapter 7	References.

1.2 Main Features of HEM-3

HEM-3 performs three main operations: dispersion modeling, estimation of population exposure, and estimation of human health risks. In order to perform these calculations, HEM-3 draws on three data libraries, which are provided with the model. The first is a library of meteorological data for over 60 stations, which are used for dispersion calculations. A second library of Census block internal point locations and populations provides the basis of human exposure calculations ([Census, 2000](#)). This Census library also includes the elevation of each Census block, which can also be used in dispersion calculations, at the option of the model user. A third library of pollutant unit risk factors and reference concentrations is used to calculate population risks. These risk factors and reference concentrations are based on the latest values recommended by EPA for hazardous air pollutants (HAP) and other toxic air pollutants.

For dispersion modeling, HEM-3 incorporates the Industrial Source Complex - Short Term, Version 3 (ISCST3) model, which is one of EPA's recommended models for assessing pollutant concentrations from industrial facilities ([EPA 1995a](#), [EPA 1995b](#)). The model handles a wide range of different source types which may be associated with an industrial source complex, including stack sources, area sources, and volume sources. HEM-3 runs ISCST3 as many times as is necessary to address the gaseous pollutants and particulate matter emitted from the target facility.

The model identifies all Census block locations within a given modeling domain, which can be specified by the user. The model's Census library includes locations and populations and elevations for all of the approximately 5.5 million Census blocks tabulated in the 2000 Census.

HEM-3 estimates cancer risks and noncancer health impacts due to inhalation exposure at Census block locations, and at other receptor locations that can be specified by the user. Cancer risks are computed using EPA's recommended unit risk factors for Hazardous Air Pollutants (HAP) and other toxic air pollutants. The resulting estimates reflect the risk of developing cancer for an individual breathing the ambient air at a given receptor site over a 70-year lifetime.

Noncancer health effects are quantified using hazard quotients and hazard indices for various target organs. The "hazard quotient" for a given chemical and receptor site is the ratio of the ambient concentration of the chemical to the level at which no adverse effects are expected. The "hazard index" for a given organ is the sum of hazard quotients for substances that affect that organ.

HEM-3 identifies receptor locations at which the predicted cancer risk and hazard indices are highest. For these locations, the model gives the concentrations of different chemicals and emission sources to overall cancer risks and hazard indices.

The model estimates the numbers of people exposed to various cancer risk levels and hazard index levels. In addition, HEM-3 estimates the average cancer risks, average hazard indices, and total incremental cancer risks for people living within different distances of the modeled emission sources.

1.3 Differences Between HEM-3 and Previous Versions of HEM

HEM was originally developed as a screening tool for exposure assessment in the 1980's ([EPA, 1986](#)). This original model has also recently been upgraded to run in a Windows™ environment ([EPA, 2002](#)). HEM-3 is designed to be somewhat more rigorous than the original HEM. The main differences between HEM-3 and the original HEM are summarized below.

- ! HEM-3 estimates cancer risks and exposures, as well as acute and chronic noncancer risks and exposures. The original version of HEM focuses mainly on cancer risks and exposures.
- ! HEM uses the ISC Long Term (ISCLT), while HEM-3 uses ISCST3. ISCST3 is more rigorous than ISCLT, but requires more time to run.
- ! HEM uses a single location for all sources at a given industrial facility, while HEM-3 requires detailed location data for each emission source at the facility.
- ! HEM can estimate exposures for all facilities in a given industrial category in the same model run. HEM-3 is designed to be run for a single facility or a small cluster of facilities in close proximity to one another. HEM-3 can be run for larger groups of facilities, but considerable time will be needed for these types of runs. In addition, a separate HEM-3 run is required for each meteorological station.

- ! HEM is designed to be run separately for each pollutant that is emitted. HEM-3 analyzes multiple pollutants concurrently.
- ! HEM-3 can take into account the impacts of pollutant deposition and plume depletion for both gaseous and particulate pollutants. These features are not included in HEM.
- ! HEM-3 can take into account the effects of terrain. This feature is not included in HEM.
- ! Both HEM and HEM-3 calculate risks for individual Census blocks, but the two models use different methods for the blocks closest to the facility. HEM models pollutant concentrations for a network of receptors (usually about 200) arranged in a polar array around the facility. Concentrations at Census blocks are then interpolated from this polar array. HEM-3 also uses a polar receptor array, but only interpolates risks for Census blocks that are far away from the facility. For Census blocks that are close to the facility, HEM-3 explicitly models concentrations and risks at the internal point given by the Census Bureau for each block.

1.4 Strengths and Limitations of HEM-3

HEM-3 performs detailed and rigorous analyses of acute and chronic air pollution risks for populations located near industrial emission sources. The HEM-3 model is designed to simplify the running of EPA's ISCST3 model without sacrificing any of the strengths of that model. In keeping with this goal, the model allows the user to specify complex emission source configurations, including point sources for stacks, area and volume sources for fugitive emissions, and obliquely oriented area sources for roadways. As noted above, the model identifies all Census blocks located near the facility. The user can also specify the locations of individual houses, schools, plant boundaries, monitors, or other receptors to be modeled by HEM-3. The model can take into account the impacts of terrain, building wake effects, pollutant deposition, and plume depletion. It also analyzes multiple pollutants concurrently, with the capability to include particulate and gaseous pollutants in the same model run.

The framework of HEM-3 has some limitations. First, the ISCST3 dispersion model, like all air pollutant dispersion models, is subject to uncertainties. Likewise, pollutant unit risk factors and reference concentrations are subject to uncertainties. Another limitation is that HEM-3 estimates pollutant concentrations and risks for a Census tract internal point, as defined by the Census Bureau. Values calculated for this internal point are not representative of the range of values over the entire block. Nor do they account for the movement of people from their home Census blocks to other Census blocks as a result of commuting or other daily activities. In addition, HEM-3 calculates outdoor concentrations of air pollutants. These do not account for indoor sources of pollution, or the attenuation of outdoor pollution in indoor air.

1.5 Requirements for Running HEM-3

HEM-3 can be used on a Windows™-based personal computer running Windows-98™ or higher. Disk space requirements will depend on the number of Census and meteorological files that will be used. If HEM-3 will only be used to model plants in a single state, the model can be run with 20 megabytes of disk space. The model also will need a minimum of 132 megabytes of RAM.

Once installed, HEM-3 can be used to model risks and exposures for any location in the U.S., and for a wide range of emission source configurations. For each model analysis, emissions inputs and emission source locations must be provided in the form of Excel™ spreadsheet files. (If Excel™ is not available, another spreadsheet program such as Lotus-123™ can be used to prepare the tables; however, they must be saved in "XLS" format.) HEM-3 requires separate estimates of emission rates of each pollutant, from each emission point. The model also requires detailed information on each emission source, including location, height, emission velocity, emission temperature, and the configuration of fugitive emission sources. An optional spreadsheet file can also be used to provide the dimensions of buildings near emission sources, which will be used to compute building wake effects. When particulate emissions are being modeled, another optional spreadsheet file can be used to provide particle size information and deposition parameters. In addition to these input files, the user is also asked to design the model receptor network and to select other modeling options through a series of user input screens.

This manual is designed to provide all of the information that is needed to run HEM-3. However, some of the options for running HEM-3 draw on advanced features of the ISCST3 dispersion model, such as the incorporation of building wake effects or plume depletion due to deposition. Users who are not already familiar with the ISCST3 dispersion model may need to refer to the manuals for that model in order to develop some of the inputs needed for HEM-3. This is particularly true for some of the more complex modeling options, such as plume depletion, building downwash, and complex source configurations. The ISCST3 manual is available from the EPA modeling website, at <http://www.epa.gov/scram001/tt22.htm#isc>

2. Installing HEM-3

2.1 Choosing the Compact or Full Version of HEM-3

The user can choose a compact version or a full version of HEM3. The compact version includes all of the software and files needed to run HEM-3, but does not include the full Census and meteorological libraries. This version is intended for users who plan to analyze exposures and risks within a limited geographical region. The user can select the appropriate Census files and meteorological files for their region, as discussed later in this section. The full version of HEM! 3 includes Census and meteorological files for the entire U.S. This version will require a longer time for installation and will take up more computer hard drive space.

Both the compact version and the full version of HEM-3 are installed using the InstallShield™ program, either from the Internet or from a CD. Once you have begun the installation process, InstallShield™ will require a few minutes to set itself up and to extract files.

The default location to install HEM-3 is “C:\Program Files\HEM3\.” The user can change this location by clicking the “Change...” button and indicating an alternate location. A screen called ‘Installing HEM3’ is displayed while the files are being copied to the destination folder. When the install is complete, the window called ‘InstallShield Wizard Completed’ appears.

2.2 Obtaining Census and Meteorological Data for the Compact Version

If the compact version of HEM-3 is selected, the user will need to obtain Census files and meteorological files for the region or regions that they are planning to model. These files are provided on the HEM-3 web page and on the HEM-3 CD.

Census files should be obtained to cover the area (or areas) within 50 kilometers of facilities that will be modeled. The files are provided on a state-by-state basis. Two files are needed for each state, a database (dbf) file, and an index (cdx) file. Multiple states may be needed to model a particular facility (if the facility is located within 50 kilometers of a state boundary). If a state is affected by two different facilities, the files for that state need only be copied once. Files are not available for partial states.

Once the user has identified the state Census files that are needed, these files must be unzipped and copied into the “Census” subdirectory under the HEM-3 directory that was selected during installation. (The default Census subdirectory is “C:\Program Files\HEM3\Census”). The user should be sure to unzip the Census files.

If the compact version of HEM-3 has been selected, meteorological files should also be obtained for the region or regions that will be modeled. Each meteorological file contains surface data and upper air data (see [Section 6.3](#)). The zip files for the meteorological files are named after the location of the surface observation site (the name of the nearest city and the state postal code). In some cases, multiple meteorological files are available for the same surface site, using different upper air observation sites. In these cases, the name of the upper air site is also included in the zip file name. Generally, the closest set of stations will be most representative of the meteorology in the modeling domain. However, there are a number of situations where a

different combination of meteorological stations will be more representative. For instance, if the modeling domain is located on the Gulf of Mexico, a surface station near the Gulf should be selected, even if there is a closer inland station.

Once the user has identified the meteorological files that are needed, these files must be unzipped and copied into the "MetData" subdirectory under the HEM-3 directory that was selected during installation. (The default meteorological subdirectory is "C:\Program Files\HEM3\MetData"). The user should be sure to unzip the meteorological files. The unzipped files will have a shorter file name, which is needed for the ISCST3 model, and a file extension of "ALL."

2.3 Obtaining Updated Chemical Data for HEM-3

HEM-3 uses a library of pollutant unit risk factors and reference concentrations is used to calculate population risks. These risk factors and reference concentrations are based on the latest values recommended by EPA, which are updated periodically. The user should check for updated versions of the HEM-3 pollutant library files on the HEM-3 web page. When these files become available, they should be copied (and unzipped) into the "Reference" subdirectory under the HEM-3 directory that was selected during installation. (The default chemical reference subdirectory is "C:\Program Files\HEM3\Reference").

3. Running HEM-3

This section is divided into three subsections. Section 3.1 discusses the preparation of input files for HEM-3. Section 3.2 discusses the selection of model options. Section 3.3 provides guidance on the modeling of multiple facilities.

3.1 Preparing Input Files

HEM-3 requires a series of Excel™ spreadsheet tables to specify the emissions and configuration of the facility (or facilities) that are to be modeled. (If Excel™ is not available, then another spreadsheet program such as Lotus-123™ can be used to prepare the tables. However, they must be saved in "XLS" format.)

At a minimum, two files are needed:

- ! a pollutant emission file
- ! an emission location file

If particulate deposition or plume depletion are to be considered, then HEM-3 will require another input file to specify the particle size distribution and scavenging parameters for various size ranges. Another optional file can be used to specify building dimensions if building wake effects are to be modeled. This option should be used if any of the emission sources are located near buildings or other obstructions which would produce wake effects. Finally, another optional input file can be used to provide the locations of houses, schools, or other sites near the emission source. HEM-3 will prompt the user to provide the input file names in a series of input screens.

Inputting directly from spreadsheets allows the user to avoid retyping the emission rates and other parameters that have been calculated. However, this method of input also has its drawbacks. Mostly, HEM-3 will not run successfully unless the input files are formatted exactly as specified in the format guidelines. Section 3.1.1 describes general rules that will help the user avoid common mistakes. Template input files are provided to make formatting easier. These files are located in the "HEM3\Input" subdirectory. Sections 3.1.2 through 3.1.6 provide detailed guidance on how to prepare the input files, and on when the optional files are needed. Template file names are also provided.

3.1.1 General rules for input files

- ! A separate file is needed for each input table.
- ! Each input file should contain only one worksheet.
- ! Columns should match exactly with the format specified for the input file. The user can do this by using the template input files and substituting actual data for the template data. (Extra lines of template data must be deleted).
- ! Columns must not be inserted between the data columns. Even if they are hidden in the spreadsheet program, HEM-3 will read these extra columns as data.
- ! There should be one header line at the top of each file.
- ! Text should not be included in numerical data fields (for instance "<0.001"). HEM-3 may read these fields as 0's or may accept only a portion of the number.

- ! When latitudes and longitudes are used, they should be in decimal degrees. (The model will also accept Universal Transverse Mercator coordinates.)
- ! The units used for parameters such as emission rates and stack parameters should match the units given in file format guidelines.

3.1.2 Input file for source locations

Tables 1 and 2 give the format guidelines for the source location input file, and a sample input table. A template input file is also provided ("Input\\Template_emission_location_file.xls").

HEM-3 can model the ambient impacts of multiple emission sources at a single facility or at a cluster of neighboring facilities. The source location file should include one record for each individual source (stack, area source, or volume source) that is to be modeled. This record provides information on the location, size, height, and configuration for each source. (Emissions data are provided in a separate file.)

The "Source ID" is a key parameter of the source location file, because it will be used to match the locations to other input files, such as the emission file. The Source ID is restricted to 8 characters (or fewer), which must be letters or numbers. Spaces cannot be used at the beginning or in the middle of the Source ID, nor can the Source ID include "-" or other typographic characters.

Each Source ID must be distinct. Different sources should be given different ID's even if they have the same location. In addition, HEM-3 cannot tell the difference between upper and lower case characters. So "ABC" and "abc" would be treated as the same Source ID.

If a cluster of facilities is to be modeled, the first few characters of the Source ID can be used to distinguish among the different facilities. For instance, "F1" for the first plant, "F2" for the second plant, and so on. This will help in the interpretation of model results for the facilities making up the cluster.

Locations can be entered in terms of Universal Transverse Mercator (UTM) coordinates, or latitude and longitude. The "coordinate system" field must be completed for each source record, in order to specify which coordinates have been used ("U" for UTM, or "L" for latitude/longitude). If UTM coordinates are used, the UTM zone must be specified (in each emission source record). If UTM coordinates are used, HEM-3 will ask the user to indicate whether the coordinates are based on the 1927 or the 1983 North American Datum (NAD). This information is needed in order to accurately calculate the distances between the emission sources and Census blocks (which are specified by latitude and longitude). The difference between UTM coordinates calculated using the 1927 and 1983 projection systems will vary from location to location, but can be as large as 100 meters.

The source type field is used to indicate whether the emission source is a point source (P), an area source (A), or a volume source (V). If the source is a point source, such as a stack or vent, the source location file must also include the source height, diameter, exit velocity, and emission release temperature.

Table 1. Format Guidelines for the Source Location File

Field	Type	Length and decimal places	Source types	Description or comment
Source ID	Character	8	all	Unique alphanumeric string up to 8 characters. No spaces or typographical symbols.
Coordinate system	Character	1	all	U = UTM, L = latitude / longitude
X-coordinate	Numeric	15,6	all	UTM east coordinate, in meters (if coordinate system = U) or decimal latitude (if coordinate system = L) of the center of point or volume sources, or the southwest corner of area sources
Y-coordinate	Numeric	15,6	all	UTM north coordinate, in meters (if coordinate system = U) or decimal latitude (if coordinate system = L) of the center of point or volume sources, or the southwest corner of area sources
UTM zone	Numeric	2,0	all	UTM zone if coordinate system = U (blank if coordinate system = L)
Source type	Character	1	all	P = point, A = area, V = volume
X-dimension	Numeric	7,0	A	Length in the easterly (or southeasterly) direction for area sources (meters)
Y-dimension	Numeric	7,0	A	Length in the northerly (or northeasterly) direction for area sources (meters)
Angle	Numeric	5,2	A	Angle of rotation (area sources only)
Lateral	Numeric	7,0	V	Horizontal dimension of volume source (meters)
Vertical	Numeric	7,0	V	Vertical dimension of volume source (meters)
Release height	Numeric	5,0	A,V	Release height (above ground) for area and volume sources (meters)
Stack height	Numeric	5,0	P	Stack release height above ground (meters)
Diameter	Numeric	5,1	P	Diameter of stack for point sources (meters)
Velocity	Numeric	7,2	P	Velocity at which emissions are coming from the stack (m/s) for point sources
Temperature	Numeric	4,0	P	Temperature of emissions for point sources (K)
Elevation	Numeric	6,0	P	Elevation of the ground above sea level at the source location (meters). Only required when using elevated terrain.

*Source types for which the parameter is needed: A = area, P = point, V = volume.

Table 2. Sample Input File for the Emission Source Locations

Source ID	Location type (U= UTM, L= lat/lon)	Longitude (dec.) or UTM E (m) [center for P or V sources, SW corner for A]	Latitude (dec.) or UTM N (m)	UTM zone	Source type (P=point, A=area, V= volume)	Length in x direction - A sources (m)	Length in y direction - A sources (m)	Angle - A sources (deg.)	Horizontal dimension - V sources (m)	Vertical dimension - V sources (m)	Release height (m) - A or V sources [use vertical cen. for V sources]	Stack height - P sources (m)	Stack diameter - P sources (m)	Exit velocity - point sources (m/sec)	Exit temperature - point sources (K)	Elevation (m)
06C00ROT	U	559966	4400652	16	P							50.3	2.82	21	322	244
06FARRFN	U	559880	4400565	16	A	130	120	0			2.0					244

An area source represents a rectangular area from which emissions emanate at ambient temperature and with negligible velocity. Area sources can be at ground level, or at a height above ground level. The default orientation for area sources is with one axis in the north-south direction, but these sources can be rotated using the “angle” parameter, which specifies the rotation of the source from north (in the clockwise direction). This feature allows the simulation of emissions from a roadway, using a long, narrow area source. The location coordinates (UTM or latitude and longitude) should reflect the southwest corner of the area source. The x-dimension should reflect the length of the source in the easterly direction, or in the southeasterly direction if the source is rotated. The y-dimension should reflect the length in the northerly direction, or the northeasterly direction if the source is rotated.

The angle parameter for area sources must be between 0 and 90 degrees, but this angle can be used to cover any possible orientation by switching the x and y dimensions. For instance, to model a road segment running from southwest to northeast, use the y-dimension to specify the road length, the x-dimension to specify the road width. To model a road segment running from northwest to southeast, use the x-dimension to specify road length and the y-dimension to specify road width.

Volume sources are specified by a horizontal dimension, a vertical dimension, and a height. Emissions from a volume source are assumed to be released at ambient temperature and with zero velocity. Both the height and the source location coordinates (UTM or latitude and longitude) should reflect the center of the source.

If terrain impacts are to be considered, the elevation above sea level should be specified for each emission source. If no elevation data are entered (and if check the elevation option is selected), then HEM-3 will estimate an elevation for the emission sources based on the elevations of nearby Census blocks.

3.1.3 Input file for emissions

Tables 3 and 4 give the format guidelines for the emissions input file, and a sample input table. A template input file is also provided (“Input\Template_HAP_emission_file.xls”).

The emissions file should contain one record for each combination of emission source and chemical. Each Source ID used in this file must match with a corresponding record in the [source location file](#).

Each chemical name used in this file must match with one of the chemical names in the HEM-3 [chemical library](#). An Excel™ table of chemical names has been provided to make this easier (“Inputs\HAP_list.xls”). Pollutants can be added to the chemical library if needed. (The user will be given the opportunity to add to or edit the library through a series of model input screens.)

The emission values should be expressed in terms of tons per year. The smallest value that can be modeled is 1E-15. If deposition or plume depletion are to be included in the model run, then HEM-3 will need the breakdown of emissions between vapor and particulate matter. The fraction emitted as particulate must be included for each emission record (each combination of source and chemical). A separate file will also be needed to specify particle sizes and scavenging coefficients. If deposition and depletion are not being considered, the particulate fraction column in the emissions input file can be left blank.

Table 3. Format Guidelines for the Emissions File

Field	Type	Length and decimal places	Description or comment
Source ID	Character	8	Must match Source ID's used in the emission location file
Pollutant	Character	50	Chemical name of the emitted pollutant. Must match a pollutant name in the chemical library . See "Inputs\HAP_list.xls" file
Emissions	Numeric	20,15	tons/year
Fraction emitted as particulate matter (%)	Numeric	7,3	%, Optional if not modeling depletion or deposition (blank if depletion and deposition are not being modeled)

Table 4. Sample Input File for Emissions

Source ID	Chemical name	Emissions (tons/year)	Fraction particulate (%)
06C00ROT	Antimony compounds	1.2E-001	100.0
06C00ROT	Chromium (VI) compounds	3.2E-004	100.0
06C00ROT	Mercury (elemental)	4.2E-002	50.0
06C00ROT	Dibenzofuran	1.1E-001	90.0
06C00ROT	Xylenes (mixed)	1.3E+000	0.0
06C00ROT	Benz(a)anthracene	7.3E-006	11.9
06C00ROT	Benzo(a)pyrene	2.5E-008	23.9
06C00ROT	Benzo(b)fluoranthene	2.8E-006	17.8
06C00ROT	Benzo(k)fluoranthene	4.6E-007	85.1
06C00ROT	Chrysene	3.2E-005	52.3
06C00ROT	Dibenz(a,h)anthracene	3.6E-008	99.3
06C00ROT	Indeno(1,2,3-cd)pyrene	1.1E-007	98.9
06FARRFN	Chromium (VI) compounds	3.8E-005	100.0
06FARRFN	Mercury (elemental)	3.6E-004	50.0
06FARRFN	Nickel compounds	4.8E-003	100.0

3.1.4 Input file for particle sizes and scavenging coefficients

If particulate matter deposition and plume depletion are to be modeled, HEM-3 will need information on the particle size distribution, and scavenging coefficients for different particle sizes. A separate input file is used to provide this information. This file should include a separate record for each particle size range emitted by each emission source. Each record must include an average particle diameter for the size range, the percentage that the size range represents in terms of the total mass of particulate matter from the given emission source, the average density of particles in the size range, and scavenging coefficients for the size range in liquid and frozen precipitation. The mass percentages should total to 100 for each emission source.

Liquid precipitation scavenging coefficients can be estimated from the correlation curve shown in [Figure 1](#), developed by [Jindal and Heinold \(1991\)](#). This correlation curve relates the coefficient to aerodynamic particulate diameter. The frozen precipitation scavenging coefficient can be estimated by dividing the wet scavenging coefficient by 3.0 ([Scire et al., 1990](#)).

Information must be provided for each of the sources listed in the [source location file](#) that emits particulate matter (as specified in the particulate fraction column of the [emissions input file](#)). Particulate information must be specified separately for each source that emits particulate matter. If the particle size and deposition information is the same for all emissions at the plant, then the information must be repeated for each emission source.

Tables 5 and 6 give format requirements for the particulate matter information file, and a sample input table. A template file is also provided ("Input\Template_particle_data.xls").

Table 5. Format Guidelines for the Particulate Matter Information File

Field	Type	Length and decimal places	Description or comment
Source ID	Character	8	Must match Source ID's used in the emission location file
Average particle diameter	Numeric	5,2	µm
Mass fraction (%)	Numeric	5,1	Must add up to 100% for each Source ID
Average particle density	Numeric	5,2	g/cm ³
Liquid precipitation scavenging coefficient (1/s-mm-h)	Numeric	7,5	Can be estimated using the correlation curve shown in Figure 1

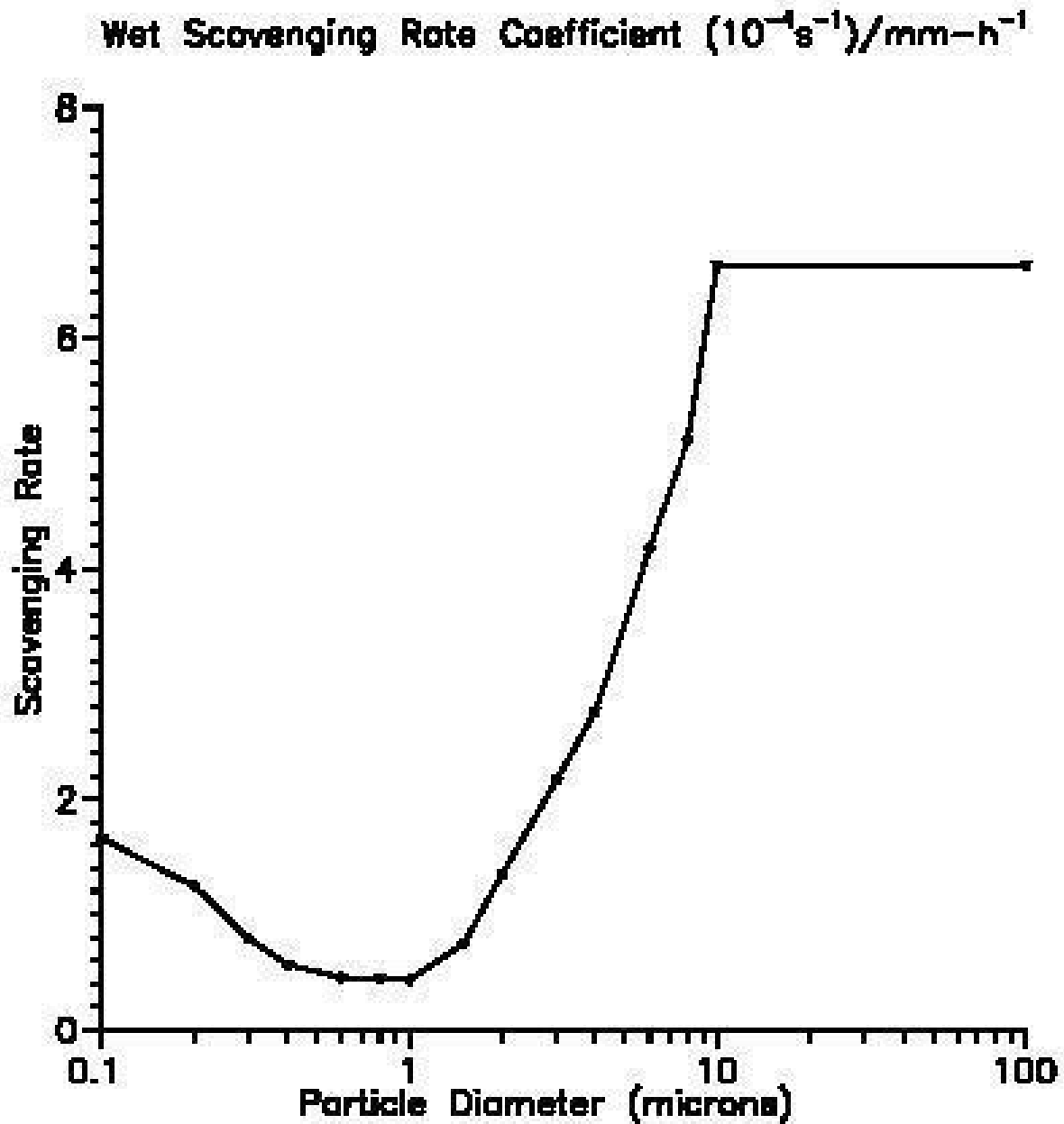


Figure 1. Wet Scavenging Coefficient as a Function of Particle Size.

Frozen precipitation
scavenging coefficient
(1/s-mm-h)

Numeric

7,5

Can be estimated by dividing the liquid
precipitation scavenging coefficient by 3

Table 6. Sample Input File for Particulate Matter Deposition Information

Source ID	Particle diameter (µm)	Mass fraction (%)	Particle density (g/cm ³)	Liquid precipitation scavenging coefficient (1/s-mm-h)	Frozen precipitation scavenging coefficient (1/s-mm-h)
06C00ROT	0.50	72.0	1.0	0.00005	0.00002
06C00ROT	1.50	8.0	1.0	0.00007	0.00002
06C00ROT	2.50	4.0	1.0	0.00019	0.00006
06C00ROT	4.00	4.0	1.0	0.00033	0.00011
06C00ROT	10.00	12.0	1.0	0.00067	0.00022
06C01RMA	0.50	72.0	1.0	0.00005	0.00002
06C01RMA	1.50	8.0	1.0	0.00007	0.00002
06C01RMA	2.50	4.0	1.0	0.00019	0.00006
06C01RMA	4.00	4.0	1.0	0.00033	0.00011
06C01RMA	10.00	12.0	1.0	0.00067	0.00022

3.1.5 Input file for building downwash

Under the regulatory option of ISCST3, the effects of building downwash should be taken into account when a building is close enough to impact dispersion from an emission source.

Building downwash will affect the predictions of ISCST3 when:

- ! the stack height is less than either 2.5 times the building height or the sum of the building height and 1.5 times the building width, and
- ! the distance between the stack and the nearest part of the building is less than or equal to five times the lesser of the height or the projected width of the building ([EPA 1995b](#), pg 1-22 and 1-23).

It should be noted that a building may impact emissions from multiple sources. In order to model the impact of building downwash, HEM-3 requires information on the projected height and width of the building when viewed in different directions from the affected emission source. For each affected source, the projected building height and width must be computed for 36 different directions, at increments of 10 degrees (compass bearing).

Building dimensions are entered using a building downwash information file. Tables 7 and 8 give format requirements for the building downwash file, and a sample input table. A template input file is also provided ("Input\Template_bldg_dimensions.xls").

Table 7. Format Guidelines Building Downwash File

Field	Type	Length and decimal places	Description or comment
Keyword	Character	6	“Height” or “Width” – specifies which values are given in this record
Source ID	Character	8	Must match Source ID’s used in the emission location file
Value 1	Numeric	6,2	Height or width (depending on the Keyword parameter) of the building looking to the north (bearing = 0) from the emission release point
Value 2	Numeric	6,2	Height or width of the building at a bearing of 10 degrees
Value n (n = 3 thru 35)	Numeric	6,2	Height or width of the building at a bearing of [(n-1)×10]
Value 36	Numeric	6,2	Height or width of the building at a bearing of 350 degrees

Table 8. Sample Input File for the Building Downwash

Keyword	Source ID	Value 1 (10°)	Value 2 (20°)	Value 3 (30°)	Value 4 (40°)	...	Value 36 (360°)
Height	06C00ROT	16.76	16.76	16.76	16.76	...	16.76
Width	06C00ROT	103.52	100.89	95.20	86.62	...	103.00

3.1.6 Input file for user-defined receptors

HEM-3 will calculate ambient impacts and resultant cancer and noncancer risks for all Census blocks within the defined modeling domain. The user can also specify additional receptor sites to be modeled, such as schools or ambient monitors. The locations of these sites are specified in the user-defined receptor file. Use a separate record to indicate the location of each user-specified receptor. If terrain effects are to be modeled, the elevation above sea level must also be provided for each user-specified receptor.

A “receptor type code” must also be specified to indicate the type of receptor. A code of “P” represents populated sites, “B” represents plant boundary sites, and “M” represents ambient monitors. A code of “P” should be used for any receptor that is to be considered in the calculation of maximum individual risk. These receptors could include houses, schools, businesses, or other populated locations.

Tables 9 and 10 give format requirements for the user-defined receptor file, and a sample input table. A template input file is also provided ("Input\\Template_user_receptors.xls").

Table 9. Format Guidelines for the User-Defined Receptor File

Field	Type	Length and decimal places	Description or comment
Coordinate system	Character	1	U = UTM, L = latitude / longitude
X-coordinate	Numeric	15,6	UTM easting coordinate, in meters (if coordinate system = U) or decimal latitude (if coordinate system = L) of the receptor
Y-coordinate	Numeric	15,6	UTM northing coordinate, in meters (if coordinate system = U) or decimal latitude (if coordinate system = L) of the receptor
Elevation (meters)	Numeric	6,0	
Receptor type code	Numeric	1	P = school, house, or other populated site; B = plant boundary; M = monitor

Table 10. Sample User-Defined Receptor File

Location type	Latitude or UTM east	Longitude or UTM north	UTM zone	Elevation (m)	Type of receptor
U	560000	441010	16	244	P
U	560005	441000	16	244	M

3.2 Selecting Model Options

Once the input files have been prepared for the modeling application, the HEM-3 program can be started. The model will display a series of forms which will require the user to select various options and to provide some additional information. These selections are discussed below.

3.2.1 Selecting the type of model run

The first user input screen will ask the user to specify some general options for the model run. HEM-3 can be used to estimate **chronic** health risks, **acute** health risks, or both. If the acute option and the plume depletion option are both selected, HEM-3 will require more time to run, since it will not be able to use ISCST3's [toxics](#) option with these selections. (The exact run time will depend on the particular source configuration and modeling domain, but the combination of acute calculations and plume depletion will generally increase run times from a few minutes to

over an hour.) Plume depletion has more of an effect on ambient concentrations farther from the plant than it does on the maximum individual risk. Therefore if plume depletion option is being included in the model run, it may save time to make two separate runs. One would calculate chronic effects and include plume depletion; and the second would calculate acute effects without depletion.

Chronic health risks are estimated based on long-term average concentrations, as predicted by ISCST3. The timeframe of this average is determined by the number of years covered by the meteorological data file selected for the model run. This is generally five years. Acute health effects are calculated from the maximum short term ambient concentrations predicted by ISCST3. There are four options for the timeframe of the short term average: 1-hour, 6-hour, 8-hour, and 24-hour.

The user will need to specify whether HEM-3 and ISCST3 should use **urban** or **rural** dispersion coefficients for the model run. EPA provides guidance on whether to select urban or rural dispersion coefficients in its [modeling guidance](#). In general, the urban option should be used if (1) the land use is classified as urban for more than 50% of the land within a 3 kilometer radius of the emission source, or (2) the population density within 3 a kilometer radius is greater than 750 people per square kilometer. Of these two criteria, the land use criterion is considered to be the more definitive.

The user will also need to specify whether HEM-3 will take into the account the impacts of **terrain elevations** in calculating ambient concentrations. Elevated terrain around the facility will generally cause ambient impacts to increase, since the emission plumes are closer to the ground. The elevation option should be selected if the height of receptors around the facility may exceed the height of any stacks at the facility. However, the option may also be selected if the elevation of terrain surrounding facility is greater than the elevation at the base of the stack but less than the height of the stack.

3.2.2 Specifying file names for emissions and source locations

The second user input screen will ask for the names of the [emission](#) file, and the [source location](#) file to be used in the current model run. This input screen also asks whether the UTM coordinates supplied in the source location file are based on the 1927 NAD or the 1983 NAD (if UTM coordinates are used). (If UTM coordinates are not used, accept the default value of 1983 NAD.)

3.2.3 Specifying options for deposition and plume depletion

The third user screen allows the user to specify whether the model will take into account the impacts of deposition and plume depletion. These processes reduce the ambient impacts from the emission source by removing pollutants from the plume. HEM-3 can consider deposition and depletion for particulate matter, gaseous pollutants, or both.

If the user opts to model deposition and depletion of particulate matter, HEM-3 will require a particulate matter input file containing particle size information and appropriate scavenging coefficients. HEM-3 will prompt the user to specify the name of the [particulate matter input file](#). If deposition and depletion of gaseous pollutants are to be modeled, HEM-3 will allow the user to specify gas scavenging coefficients for liquid and frozen precipitation. The default values for gas

scavenging coefficients are currently set at levels equal to scavenging coefficients for very fine particulate matter ([Figure 1](#)).

3.2.4 Specifying file names for building dimensions and particulate matter

The fourth input screen allows the user to specify whether HEM-3 will model the effects of building downwash. Section 3.1.5 summarizes situations where building downwash should be taken into account. If the building downwash option is selected, HEM-3 will prompt the user for the name of the building dimension file ([see Section 3.1.5](#)).

This input screen also includes an option to edit the library of chemical risk factors and noncancer benchmarks. If this option is selected, the user will be given the opportunity to edit the chemical library in a later screen.

3.2.5 Defining the modeling domain

The fifth user input screen allows the user to define the modeling domain by specifying the following information.

Outside radius. The modeling domain input screen allows the user to specify the outside radius of the modeling domain, or the area for which ambient impacts are to be modeled. This distance is usually 30 to 50 kilometers. The center of this area is generally the geographical center of the facility (or facilities) being modeled, but this location can be adjusted in a later input screen.

Inside radius. An inside radius for the modeling domain can also be specified, but generally this radius should be set to 0. HEM-3 provides the option of changing this value in case it becomes necessary to divide a modeling job in order to make more efficient use of computer resources. For instance, one run could be used to model all receptors from 0 to 10,000 meters from a facility, and a second run could be used for receptors located between 10,000 and 50,000 meters from the same facility. In this case, the maximum individual risk would be the maximum value for the two runs, and the population exposure to any given risk level would be the sum of population exposures for the two runs.

Distance for individual modeling of Census blocks. The modeling domain input screen will also ask the user to specify the cutoff distance for individual modeling of Census blocks. Within this radius, each block will be modeled explicitly as a receptor using ISCST3. Outside of this radius, Census blocks will not be modeled individually, but ambient impacts will instead be interpolated using ISCST3 results for a polar receptor network, described below. Larger values for this cutoff distance will require more time to model, because the number of Census block receptors will be higher. However, this cutoff value should be set at a large enough distance so that at the maximum individual risk receptor will be modeled individually. This distance will vary depending on the configuration of the source, but it generally is between 1500 and 2000 meters.

Overlap distance. The user can also specify a distance within which sources and receptors will be considered to be overlapping. This feature is provided in order to address the situation where Census blocks are very close to a facility and have complex shapes. In such cases, the centroid of a Census block may be much closer to the facility than the nearest actual dwelling. (In fact, if a Census block surrounds a portion of the facility, the centroid of the block will be on plant property.) The default value for the overlap distance is set to 30 meters, or approximately

equal to the width of a narrow buffer and a roadway. If a receptor falls within this distance, HEM-3 will not calculate risks based on the location of that receptor, but will instead assume that the risks associated with the receptor are the same as the highest predicted value for any receptor that does not overlap plant property (even if it is not a population receptor).

Polar receptor network. As noted above, a polar receptor network will be used to interpolate risk values for Census blocks outside of the individual block modeling distance. The user can specify the number of concentric circles and the number of radial directions to be included in this polar network. A typical run would include 13 concentric rings and 12 or 16 radial directions. HEM-3 will distribute the radial directions evenly around the plant. For instance, if 16 directions are chosen, receptors will be modeled at compass bearings of 0, 22.5, 45, 67.5, 90, 112.5, 135, 157.5, 180, 202.5, 225, 247.5, 270, 292.5, 315, and 337.5. The selection of specific ring distances is discussed in Section 3.2.7.

3.2.6 Checking the HEM-3 inputs

After the modeling domain input screen, the input verification screen will ask the user to verify all of the choices that have been made. To change a selection, check the appropriate box and then click "OK." The selected parameter can then be edited.

3.2.7 Changing the suggested model ring distances

HEM-3 will recommend a list of polar ring distances based on the number of rings that have been specified in the modeling domain input screen. These recommendations will be a logarithmic progression of distances starting 100 meters from the center of the source and ending at the outer radius of the modeling domain. (For large sources, some of these rings may overlap plant property.) The ring distance input screen allows the user to alter the recommended ring distances to fit the specific size and surroundings of the facility (or facilities) that are being modeled. The ring distances will be used for interpolating risks at Census blocks outside of the modeling cutoff distance. In addition, the model will calculate the exposed populations and average risks within each of the rings specified in this screen.

3.2.8 Checking the facility location and the domain center

The location check screen provides a number of options for viewing the facility location in relation to other nearby geographic features. The user can view the location on a Geographic Information System (GIS) map, an aerial photograph, or a topographical map. HEM-3 calculates the geographic center using the combination of all emission sources listed in the source location file. To generate the GIS map, HEM-3 provides the location of the modeled facility to EPA's EnviroMapper website. The aerial photograph and the topographic map are generated by calling the Terraserver™ website, operated by Microsoft.

HEM-3 allows the user to use the geographic center of the emission sources as the center for the modeling domain, or to specify different coordinates to meet the needs of the analysis. The center of the modeling domain will be used in interpolating risks at Census blocks outside the modeling cutoff distance. In addition, HEM-3 will calculate the total population and average risks within various distances from the modeling domain center. It may be desirable to change the domain center if the facility includes an outlying emission source, such as a storage tank farm or a ship-loading facility. In that case, the default condition of HEM-3 would be to place the domain center midway between the main process operation and the outlying source. In this case, the

domain center can be moved closer to the main process operation, especially if the outlying facility is a small source of emissions.

3.2.9 Selecting a meteorological station

The meteorological station input screen allows the user to select an appropriate meteorological input file for the modeling domain. HEM-3 includes a library of processed meteorological data for over 60 sites. Each meteorological input file includes preprocessed upper air data and surface data as discussed in [Section 6.3](#). HEM-3 calculates the distances from all of the surface and upper air stations to the center of the modeling domain. The meteorological input screen then ranks the available files according to their proximity to the modeling domain.

Generally, the closest set of stations will be most representative of the meteorology in the modeling domain. However, there are a number of situations where a different combination of meteorological stations will be more representative. For instance, if the modeling domain is located on the Gulf of Mexico, a surface station near the Gulf should be selected, even if there is a closer inland station. HEM-3 also allows the user to provide a meteorological data file for the specific facility location. (This file must be preprocessed and formatted for ISCST3, as discussed in [Section 6.3](#), and placed in the “HEM3Metdata” subdirectory). If the user does not specify a particular set of surface and upper air station, the closest available set of stations will be selected.

3.2.10 Changing the chemical risk factors and health benchmarks

If the user has elected to edit the chemical library (in the file name screen), an edit screen will be displayed. This screen allows cancer risk factors and noncancer reference concentrations to be changed for the chemicals that are in the library. New chemicals can also be added to the library.

When adding new chemical names to the library, the user should make sure to use the same spelling that has been used in the [emissions input file](#). The CAS number and HAP number fields in the chemical library are optional. If a cancer risk factor is not specified for a new chemical, then the cancer risk factor will be assumed to be 0. If noncancer reference concentration is not specified for a new chemical, then the chemical will be assumed to have no noncancer effects.

3.2.11 Checking the facility configuration and nearby receptors

After the user has checked the location of the facility and specified the modeling domain, HEM-3 identifies the Census blocks within the modeling domain. The model then produces a plot showing the source configuration and the locations of the nearest Census block receptors.

If any of the receptors overlap the facility, HEM-3 will not calculate risks based on the location of that receptor, but will instead assume that the risks associated with the receptor are the same as the highest predicted value for any receptor that does not overlap plant property. Therefore, the user should enter a series of boundary receptors to make sure that the maximum risks for the overlapping receptors are properly characterized.

3.3 Modeling Multiple Facilities

HEM-3 can be used to analyze the impacts of a single industrial facility or a cluster of facilities located near one another. The main factor limiting the number of facilities that can be modeled is the time that will be required to run ISCST3. This required runtime will be roughly proportional to the product of the number of emission source locations and the number of receptors that are modeled. The number of receptors modeled includes the polar receptor network, all of the Census blocks that are modeled individually (see [Distance for individual modeling of Census blocks](#) under Section 3.1.5), and any receptor locations defined by the user (see [Section 3.1.6](#)). It should be noted that the cutoff distance for individual modeling of Census blocks applies to all emission source locations, not just to the center of the modeling domain. This feature of HEM-3 is designed to ensure that calculated maximum individual risks and hazard indices will be based on actual dispersion model results, rather than interpolation. As a consequence of this feature, the number of individually modeled Census blocks will depend on how close the facilities are to one another. For instance, if a model cutoff distance of 2 kilometers is chosen for a cluster of two facilities located 100 meters apart, the number of individually modeled Census blocks would not be much larger than if only one facility were being modeled. However, the number of individually modeled Census blocks would likely double if the facilities were 2 kilometers apart. (The exact numbers would depend on the population density in the modeling domain.)

The [interpolations](#) performed in HEM-3 will become less accurate as distances increase between the modeled facilities. This will primarily affect exposure calculations, such as the number of people estimated to be exposed to different risk levels. The accuracy of maximum individual risks and maximum hazard indices will generally be affected, since these values are not interpolated unless the selected cutoff distance is too small. (HEM-3 will show a warning message when this occurs.)

The HEM-3 output files allow the user to distinguish the contributions of different emission sources to the maximum individual risk or maximum hazard indices (see [Sections 5.1 and 5.2](#)). When a cluster of facilities is modeled, the first few characters of the [Source ID](#) can be used to distinguish among the different facilities. For instance, "F1" for the first plant, "F2" for the second plant, and so on. This will help in the interpretation of model results for the facilities making up the cluster.

It should be noted that the location of the maximum individual risk for a cluster of facilities may be different from the location of the maximum individual risk for any member of the cluster. Therefore, it may be desirable to model the facilities in the cluster separately as well as together.

4. Calculations Performed by HEM-3

4.1 Dispersion Modeling

HEM-3 carries out dispersion modeling by running the ISCST3 model. ISCST3 is one of EPA's suite of recommended models for industrial source complexes. Section 3 has described a number of options that the user of HEM-3 can specify for the running of ISCST3, for instance whether to incorporate deposition and depletion, and whether to use urban or rural dispersion parameters. This section describes the options which are implemented automatically by HEM-3. In addition, we describe the dilution factor methodology, which is used in HEM-3 for modeling multiple pollutants.

4.1.1 Regulatory default option

HEM-3 uses the regulatory default options when running ISCST3. These options include the following:

- ! Use stack-tip downwash (except for Schulman-Scire downwash)
- ! Use buoyancy-induced dispersion (except for Schulman-Scire downwash)
- ! Do not use gradual plume rise (except for building downwash)
- ! Use the calms processing routines
- ! Use upper-bound concentration estimates for sources influenced by building downwash from super-squat buildings
- ! Use default wind profile exponents
- ! Use default vertical potential temperature gradients.

4.1.2 Toxics option

The deposition and plume depletion options of ISCST3 require longer run times than simple ambient impact calculations. Therefore, when these options are selected, HEM-3 invokes the ISCST3 toxics option for modeling of chronic risks. Under this option, ISCST3 does not model each hour separately, but uses a statistical sample of the hourly meteorological data. This option is not used to model acute risks, since these are based on the maximum hourly concentration.

4.1.3 Dilution factors

To save time when analyzing the impacts of multiple pollutants, HEM-3 does not model each pollutant separately. Instead, ISCST3 is used to compute a series of dilution factors, specific to each emission source and receptor. The dilution factor for a particular emission source and receptor is defined as the predicted ambient impact from the given source and at the given receptor, divided by the emission rate from the given source. The dilution factor does not vary from pollutant to pollutant, as long as the pollutants have common deposition and degradation properties. In HEM-3, separate dilution factors are computed for particulate matter emissions and for gaseous emissions. In this way, the model can account for the effects of deposition and plume depletion separately for particulate matter and gases. In addition, different particle sizes, densities, and scavenging coefficients can be specified for each emission source.

4.2 Estimating Risks and Hazard Indices

HEM-3 estimates total cancer risks and hazard indices for all Census block locations in the modeling domain, all user-defined receptors, and all points in the polar receptor network. [Section 4.2.1](#) describes methods used to calculate cancer risks and hazard indices for receptors that are explicitly modeled using ISCST3. [Section 4.2.2](#) describes the interpolation approach used to estimate cancer risks and hazard indices at Census blocks that are not explicitly modeled.

Based on the results for Census blocks and other receptors, HEM-3 estimates the maximum individual risk and maximum hazard indices for populated receptors ([Section 4.2.3](#)); as well as the maximum impacts for all offsite receptors, including unpopulated locations ([Section 4.2.4](#)). For these locations, the model calculates the contributions of individual chemicals and emission sources to cancer risks and hazard indices ([Section 4.2.5](#)).

4.2.1 Inner Census blocks and other modeled receptors

HEM-3 calculates cancer risks and target-organ-specific hazard indices for three types of discrete receptors. These are (1) Census blocks within the user-defined [distance cutoff](#) for modeling of individual blocks, (2) all [user-defined receptors](#), and (3) the user-defined [polar receptor network](#).

As noted in the previous section on [dilution factors](#), HEM-3 combines pollutants into two categories – gases and particulates – for the purposes of dispersion modeling. In order to conserve computer memory capacity, the model retains these categories to calculate cancer risks and noncancer hazard indices. The following algorithms are used.

For cancer risk:

$$CR_T = G_{i,j} CR_{i,j}$$

$$CR_{i,j} = DF_{i,j} \times CF \times G_k [E_{i,k} \times URE_k]$$

For noncancer hazard indices:

$$HI_T = G_{i,j} HI_{i,j}$$

$$HI_{i,j} = DF_{i,j} \times CF \times HWE_{i,j} = G_k [E_{i,k} \times RC_k]$$

where:

- CR_T = total cancer risk at a given receptor (probability for one person)
- $G_{i,j}$ = the sum over all sources i and pollutant types j (particulate or gas)
- $CR_{i,j}$ = cancer risk at the given receptor for source i and pollutant type j
- $DF_{i,j}$ = dilution factor $[(\mu\text{g}/\text{m}^3) / (\text{g}/\text{sec})]$ at the given receptor for source i and pollutant type j
- CF = conversion factor, $0.02877 [(\text{g}/\text{sec}) / (\text{ton}/\text{year})]$
- G_k = sum over all pollutants k within pollutant group j (particulate or gas)
- $E_{i,k}$ = emissions of pollutant k from source i
- URE_k = cancer unit risk factor for pollutant k

HI_T = total organ-specific hazard index at a given receptor and for a given organ
 $HI_{i,j}$ = organ-specific hazard index at the given receptor for source i and pollutant type j
 RC_k = noncancer health effect reference concentration for pollutant k

The above equations are equivalent to the following simpler equations:

$$CR_T = G_{i,k} AC_{i,k} \times URE_k$$

$$HI_T = G_{i,k} AC_{i,k} / RC_k$$

where:

$AC_{i,k}$ = ambient concentration ($\mu\text{g}/\text{m}^3$) for pollutant k at the given receptor. This is the same as $[E_{i,k} \times DF_{i,j} \times CF]$

However, these simpler equations would require that all pollutants be modeled individually in ISCST3, and that risk calculations be performed separately for each pollutant.

If the cancer unit risk factor is not available for a given chemical, then that chemical is not included in the calculation of cancer risk. Likewise, if the noncancer reference concentration is not available for a given chemical, that chemical is not included in the calculation of hazard indices. Note also that separate reference concentrations are used for acute and chronic hazard indices.

4.2.2 Outer Census blocks

For Census blocks outside of the user-defined [distance cutoff](#) for individual block modeling, HEM-3 estimates cancer risks and hazard indices by interpolation from the [polar receptor network](#). The interpolation is linear in the angular direction, and logarithmic in the radial direction, as summarized in the following equations:

$$I_{a,r} = I_{1,r} + (I_{2,r} - I_{1,r}) \times (a - A1) / (A2 - A1)$$

$$I_{A1,r} = \exp\{\ln(I_{A1,R1}) + [\ln(I_{A1,R2}) - \ln(I_{A1,R1})] \times [\ln(R) - \ln(R1)] / [\ln(R2) - \ln(R1)]\}$$

$$I_{A2,r} = \exp\{\ln(I_{A2,R1}) + [\ln(I_{A2,R2}) - \ln(I_{A2,R1})] \times [\ln(R) - \ln(R1)] / [\ln(R2) - \ln(R1)]\}$$

where:

$I_{a,r}$ = the impact (cancer risk or hazard index) at an angle, a, from north, and radius, r, from the center of the modeling domain
 a = the angle of the target receptor, from north
 r = the radius of the target receptor, from the center of the modeling domain
 A1 = the angle of the polar network receptors immediately counterclockwise from the target receptors
 A2 = the angle of the polar network receptors immediately clockwise from the target receptor
 R1 = the radius of the polar network receptors immediately inside the target receptor
 R2 = the radius of the polar network receptors immediately outside the target receptor

4.2.3 Maximum individual risks and hazard indices

HEM-3 evaluates the predicted impacts for all populated receptors in order to identify the locations of the maximum individual cancer risk and the highest hazard indices for various target organs. For these calculations, populated receptors include all Census block locations, and any user-defined receptors that are designated as type-P. In general, type-P receptors should include houses near the facility boundary, as well as nearby schools, public places, or other populated sites.

It should be noted that the maximum cancer risk may occur at a different location than the maximum hazard index for a given organ. Likewise, the location of the maximum hazard index for one organ will not necessarily be the same as the location for a different organ. HEM-3 performs a separate evaluation of the maximum impact location for each health effect.

The model also tests for instances where Census blocks or other P-type receptors appear to be located on plant property. This is done by calculating the distance between each receptor and each emission source. These distances are compared with an [overlap distance](#), which can be specified by the user. If a populated receptor is located within the overlap distance, then the calculated results for this receptor are not used to estimate the maximum individual cancer risk or maximum hazard indices for populated areas. Instead, the impacts at the overlapping receptor are assumed to be equal to the maximum impacts for any receptors that do not overlap plant property. This could include both populated and unpopulated receptors, as long as they do not overlap plant property.

4.2.4 Maximum offsite impacts

In addition to evaluating the maximum cancer risks and hazard indices for populated receptors, HEM-3 also evaluates maximum offsite impacts for all receptors. All Census blocks, all user-defined receptors (populated and unpopulated), and all points on the polar receptor network are included in the evaluation of maximum offsite impacts, except for those receptors that are found to be overlapping emission sources.

4.2.5 Contributions of different chemicals and emission sources

HEM-3 calculates the contributions of different chemicals and emission sources to cancer risks and hazard indices at the receptors where impacts are highest, both for populated receptors and for all offsite receptors. As noted in [Section 4.2.1](#), HEM-3 conserves computer disk space by grouping chemicals together when calculating total risks and hazard indices for the large number of receptors that are typically included in an overall modeling domain. Thus, the contributions of individual chemicals and emission sources are not computed for all receptors. However, HEM-3 retains the information needed to determine the contributions of individual chemicals and emission sources at the receptors where impacts are highest. These contributions are calculated using the following equations:

$$AC_{i,k,m} = E_{i,k} \times DF_{i,j,m} \times CF$$

$$CR_{i,k,m} = AC_{i,k,m} \times URE_k$$

$$HQ_{i,k,m} = AC_{i,k,m} + RC_k$$

where:

$AC_{i,k,m}$	=	predicted ambient concentration for chemical k, from source i, at receptor m
$E_{i,k}$	=	emissions of pollutant k from source i
$DF_{i,j,m}$	=	the dilution factor for source i, receptor m, and pollutant group j, which includes pollutant k
CF	=	conversion factor, 0.02877 [(g/sec) / (ton/year)]
$CR_{i,k,m}$	=	estimated cancer risk from source i, and pollutant k, at receptor m
URE_k	=	cancer unit risk factor for pollutant k
$HQ_{i,k,m}$	=	organ-specific hazard quotient as a result of emissions of pollutant k, from source i, at receptor m
RC_k	=	noncancer health effect reference concentration for pollutant k

4.3 Population Exposures, Average Impacts and Total Risks

Using the predicted impacts for Census blocks, HEM-3 estimates the populations exposed to various cancer risk levels and hazard index levels. This is done by adding up the populations for receptors that have predicted cancer risks or hazard indices above the given threshold.

The model also calculates the average cancer risks, average hazard indices, and total cancer risks for Census blocks located within various distances of the emission sources. The following equations are used:

$$MCR_d = G_m [CR_m \times P_m] + G_m P_m$$

$$MHI_d = G_m [HI_m \times P_m] + G_m P_m$$

$$TCR_d = G_m [CR_m \times P_m] + LT$$

where:

MCR_d	=	the population-weighted average cancer risk for the population located within distance d of the center of the modeling domain
G_m	=	the sum over all Census blocks m within distance d
CR_m	=	the total lifetime cancer risk (from all modeled pollutants and emission sources) at Census block m
P_m	=	the population at Census block m
MHI_d	=	the population-weighted average hazard index (for a particular organ) for the population located within distance d
HI_m	=	the total hazard index for the given organ (from all modeled pollutants and emission sources) at Census block m
TCR_d	=	the estimated total annual cancer risk (cancers/year) to the population living within distance d
LT	=	the average lifetime used to develop the cancer unit risk factor, 70 years

HEM-3 also estimates the contributions of different chemicals and emission sources to total cancer risks for the overall modeling domain. The following equations are used:

$$TCR_{i,j} = G_m [(G_k E_{i,k} \times URE_k) \times DF_{i,j,m} \times CF + LT]$$

$$TCR_{i,k} = TCR_{i,j} \times E_{i,k} \times URE_k \cdot \left(G_k E_{i,k} \times URE_k \right)$$

where:

- $TCR_{i,j}$ = the estimated total annual cancer risk (cancers/year) to the population in the modeling domain due to emissions from pollutant type j (1= particulate, 2=gas) and emission source i
- G_m = the sum over all Census blocks m in the modeling domain
- G_k = the sum over all pollutants k, within pollutant type j
- $E_{i,k}$ = emissions of pollutant k from source i (tons/year)
- URE_k = unit risk factor for pollutant k
- $DF_{i,j,m}$ = dilution factor at receptor m, for emissions of pollutant type j (which includes pollutant k), from source i
- CF = conversion factor, 0.02877 [(g/sec) / (ton/year)]
- $TCR_{i,k}$ = the estimated total annual cancer risk (cancers/year) to the population in the modeling domain due to emissions of pollutant k (in pollutant type j) from emission source i

5. Outputs of HEM-3

After running the dispersion model and completing the necessary risk and exposure calculations, HEM-3 displays a series of output tables. All of these tables are also copied to spreadsheets in Excel™ format in the “HEM3\Outputs” subdirectory. (If Excel™ is not available, these files can also be read by another spreadsheet program, such as Lotus-123™.) HEM-3 also produces a number of more detailed database and spreadsheet files which can be used for more in-depth analyses, such as GIS analysis or analyses of demographic data. The following sections describe the output tables and files produced by HEM-3.

5.1 Maximum Individual Risks

The maximum individual risk screen displays a table showing the highest cancer risks and hazard indices (HI) predicted for any populated receptor that does not overlap plant property. If any populated receptor is located within the minimum overlap distance, then the calculated results for that receptor are not used. Instead, the maximum cancer risk and hazard indices are assumed to be equal to the maximum impacts for any receptor that does not overlap plant property. This could include both populated and unpopulated receptors, as long as they do not overlap plant property.

A separate line is displayed for each health effect: cancer risk; chronic hazard indices for the respiratory system, the liver, the neurological system, developmental effects, the reproductive system, the kidney, the ocular system, the endocrine system, the hematological system, the immunological system, the skeletal system, the spleen, the thyroid, and whole body effects. Table 11 shows the fields displayed on the maximum individual risk screen.

Cancer risks are computed using EPA's recommended unit risk factors for HAPs and other toxic air pollutants. The resulting estimates reflect the risk of developing cancer for an individual breathing the ambient air at a given receptor site over a 70-year lifetime. Noncancer health effects are quantified using hazard quotients and hazard indices for various target organs. The “hazard quotient” for a given chemical and receptor site ratio of the ambient concentration of the chemical to the level at which no adverse effects are expected. The “hazard index” for a given organ is the sum of hazard quotients for substances that affect that organ.

Data will only be displayed if the maximum cancer risk or hazard index is greater than 0. The user can view the contribution of different chemicals to the maximum cancer risk, or to any of the hazard indices by highlighting the appropriate line and then clicking the “details by pollutant” button. The pollutant contributions to the maximum cancer risk will be displayed in order of impact (highest impact first). Likewise, the contribution of different emission sources can be viewed by highlighting the appropriate line and clicking the “details by source” button.

Table 11. Fields Included in the Maximum Individual Risk and Maximum Offsite Impact Displays

Field	Description
Parameter name	cancer risk, respiratory HI, CNS HI, cardiovascular HI, blood HI, liver HI, kidney HI, immune system HI, and total acute HI
Value	maximum individual cancer risk or maximum hazard index
Population	at the location of the maximum cancer risk or hazard index, if it is a Census block
Distance	from the center of the modeling domain
Angle	from north
Elevation	above sea level
Receptor type	C = Census block, P = user-defined population receptor, G = polar receptor grid point, B = boundary, M = monitor
Notes	An entry in this field will generally mean that the modeling analysis should be rerun. This field will provide advice on how to change model input files or other specifications.
County FIPS code	if the receptor is a Census block
Census block identifier	for linking to demographic data (if the receptor is a Census block)
UTM east coordinate	meters
UTM north coordinate	meters
Latitude	decimal
Longitude	decimal

The user can also highlight any of the receptor lines and click the “GIS map” button to view an EnviroMapper GIS map centered on the receptor location. The “source map” button will display the locations of the maximum cancer risk and maximum total chronic hazard index receptors in comparison to the locations of emission sources.

Click the “Next” button to move to the next results screen.

HEM-3 automatically produces an Excel™ file entitled “maximum_indiv_risks.xls” which includes all of the data tabulated on this screen. In addition, an Excel™ file entitled “MIR_bkdn.xls” is produced giving the contributions of individual chemicals and emission sources to the maximum cancer risk and maximum hazard indices. The file also breaks down the contributions of gaseous and particulate emissions for any chemicals that are emitted in both forms. Table 12 shows the fields included in the chemical and source contribution file “MIR_bkdn.xls” file.

**Table 12. Fields Included in the Chemical and Source Contribution File
(MIR_bkdn.xls and MOI_bkdn.xls)**

Field	Description
Site type	maximum individual risk, or maximum offsite impact
Parameter name	cancer risk, respiratory HI, CNS HI, cardiovascular HI, blood HI, liver HI, kidney HI, immune system HI, and total acute HI
Source ID	maximum individual cancer risk or maximum hazard index
Pollutant	
Pollutant type	P = particulate, V = vapor
Angle	from north
Risk	cancer risk or hazard quotient (HQ)
Concentration	pollutant concentration ($\mu\text{g}/\text{m}^3$)

5.2 Maximum Offsite Impacts

The maximum offsite impact screen displays a table showing the highest cancer risks and HI predicted at any receptor that does not overlap with the emission sources, whether the receptor is populated or unpopulated. The receptors included in this calculation include all Census blocks, all user-defined receptors (including boundary sites and ambient monitor sites), and all points in the polar receptor network, except for those receptors which overlap with emission sources.

The format is the same as in the Maximum Individual Risk output screen. A separate line is displayed for each health effect: cancer risk; chronic HI's for the respiratory system, CNS, cardiovascular system, blood, liver, kidney, and immune system; and total acute hazard index. Table 11 shows the fields displayed on the maximum individual risk screen. Data will only be displayed if the maximum cancer risk or hazard index is greater than 0.

The contribution of different chemicals to the maximum cancer risk, or to any of the hazard indices, can be viewed by highlighting the appropriate line and then clicking the "details by pollutant" button. Likewise, the user can view the contribution of different emission sources by highlighting the appropriate line and clicking the "details by source" button. In addition, the user can highlight any of the receptor lines and click the "GIS map" button to view an EnviroMapper GIS map centered on the receptor location.

Click the "next" button to move to the next results screen.

HEM-3 automatically produces an Excel™ file entitled "maximum_offsite_impact.xls" which includes all of the data tabulated on this screen. In addition, an Excel™ file entitled "MOI_bkdn.xls" is produced giving the contributions of individual chemicals and emission sources to the maximum cancer risk and maximum hazard indices. The file also breaks down the contributions of gaseous and particulate emissions for any chemicals that are emitted in

both forms. Table 12 shows the fields included in the chemical and source contribution file "MOI_bkdn.xls" file.

5.3 Domain-Wide Population Exposures

The domain wide population exposure screen presents two tables, which estimate the populations exposed to different cancer risk levels and to different hazard indices for noncancer effects. Tables 13 and 14 show sample population exposure tables for cancer, and for noncancer impacts, respectively. HEM-3 automatically creates two Excel™ files entitled "Cancer_risk_exposure.xls" and "Noncancer_risk_exposure.xls," which contain the information given in Tables 13 and 14, respectively.

Table 13. Sample Output Table for Cancer Risk Exposure

Cancer risk level	Population
Greater than or equal to 1 in 1,000	0
Greater than or equal to 1 in 10,000	2
Greater than or equal to 1 in 20,000	101
Greater than or equal to 1 in 100,000	2,233
Greater than or equal to 1 in 1,000,000	263,631
Greater than or equal to 1 in 10,000,000	2,310,368

Table 14. Sample Output Table for Noncancer Risk Exposure

Level of total chronic hazard index	Populations exposed to hazard indices above the noted level							Total acute HI
	Total chronic HI	Respiratory HI	Liver HI	Neurological HI	Developmental HI	Reproductive HI	...	
Greater than or equal to 1 in 100	0	0	0	0	0	0	...	0
Greater than or equal to 1 in 50	0	0	0	0	0	0	...	0
Greater than or equal to 1 in 10	0	0	0	0	0	0	...	0
Greater than or equal to 1 in 1.0	0	0	0	0	0	0	...	862,475
Greater than or equal to 1 in 0.5	0	0	0	0	0	0	...	1,456,614
Greater than or equal to 1 in 0.2	0	0	0	0	0	0	...	1,457,673

5.4 Cancer Risk by Distance

The distance-based and risk screen displays the average cancer risk and the estimated total potential annual cancer impact for the populations living within each of the ring distances specified for the [polar receptor network](#). This screen also displays the total population for all of the Census blocks with geographic centroids inside each ring distance. HEM-3 automatically creates an Excel™ file entitled "Risk_by_distance.xls," which contains the information given in Table 15.

Table 15. Sample Output Table for Cancer Exposure at Different Distances

Distance (m)	Population	Average cancer risk to an individual	Total potential cancer impact (number of cases per year)
100	0	na	na
180	0	na	na
320	0	na	na
570	0	na	na
1,000	628	2.4e-08	2.2e-07
1,600	7,250	2.2e-08	2.3e-06
2,600	23,569	1.8e-08	6.5e-06
4,200	58,522	1.4e-08	1.4e-05
6,800	158,787	9.0e-09	2.6e-05
11,100	374,763	5.6e-09	4.4e-05
18,100	851,851	3.4e-09	6.6e-05
29,500	1,291,629	2.1e-09	7.9e-05
50,000	1,457,279	1.0e-09	8.2e-05

5.5 Additional Output Files

In addition to the Excel™ output files discussed above, HEM-3 produces four Dbase™-formatted output files that give total cancer risks and hazard indices for all of the modeled receptors and interpolated receptors in the modeling domain. These files are entitled:

- ! Block_summary_chronic.dbf
- ! Block_summary_acute.dbf
- ! Ring_summary_chronic.dbf
- ! Ring_summary_acute.dbf

The “chronic” files give the total estimated cancer risk at each receptor, as well as total and organ-specific hazard indices for chronic noncancer effects. The “acute” files give the total hazard index of acute noncancer effects at each receptor. The “block summary” files give results for the Census block locations, and the “ring summary” file provide give results for points in the polar receptor network.

In addition to cancer risk estimates and hazard indices, each file gives the latitude and longitude, and the UTM coordinates of each receptor. These are intended to facilitate detailed GIS analyses of HEM-3 results. The “block summary” files also give the county FIPS code, block identification number, and population of each Census block. This information is intended to facilitate studies linking HEM-3 results with Census information, such as demographic or economic data.

6. HEM-3 Data Libraries

6.1 Chemical Health Effects Information

HEM-3 includes a library of available health effects data for HAPs. For each pollutant, the library includes the following parameters, where available:

- ! unit risk factor for cancer
- ! reference concentration for chronic noncancer health effects
- ! reference concentration for acute health effects
- ! target organs affected by the chemical

These parameters have been taken from EPA's database of recommended unit risk factors and reference concentrations for HAPs.

6.2 Census and Elevation Data

The HEM-3 Census library includes the locations, and populations for all of the over 5 million Census blocks identified in the 2000 Census. These data were extracted from the LandView® database ([Census, 2000](#)). The Census library also includes calculated elevations for all of the Census block locations. The block elevations were interpolated from the U.S. Geological Service's 1:250,000 Digital Elevation Model data ([USGS, 2003](#)). These data have a resolution of 3 arc seconds, or about 90 meters.

6.3 Meteorological Data

ISCST3 requires surface and upper air meteorological data that meet specific format requirements ([EPA, 1998a](#)). Meteorological observations are collected at a large number of surface and upper air stations across the country; however, not all of these data are suitable to be used with ISCST3. HEM-3 includes a library of over 60 meteorological data files that combine surface and upper air observations. [Figure 2](#) shows the locations of surface and upper air stations used to produce these input files. These data have been preprocessed to produce files suitable for use in ISCST3.

Surface data in the HEM-3 library have been obtained from two data sources. The first is a joint EPA/National Oceanic and Atmospheric Administration (NOAA) database of "Hourly United States Weather Observations," or HUSWO (EPA/NOAA). This database contains observations data from 1990-1995, the most recent compilation of the surface data needed in the required format. If previous years of data were required, this information was extracted from a joint NOAA/National Renewable Energy Laboratory (NREL) data product, "Solar and Meteorological Surface Observation Network," or SAMSON (NOAA/NREL). Upper air data were obtained from a databases produced by NOAA, "Radiosonde Data of North America."

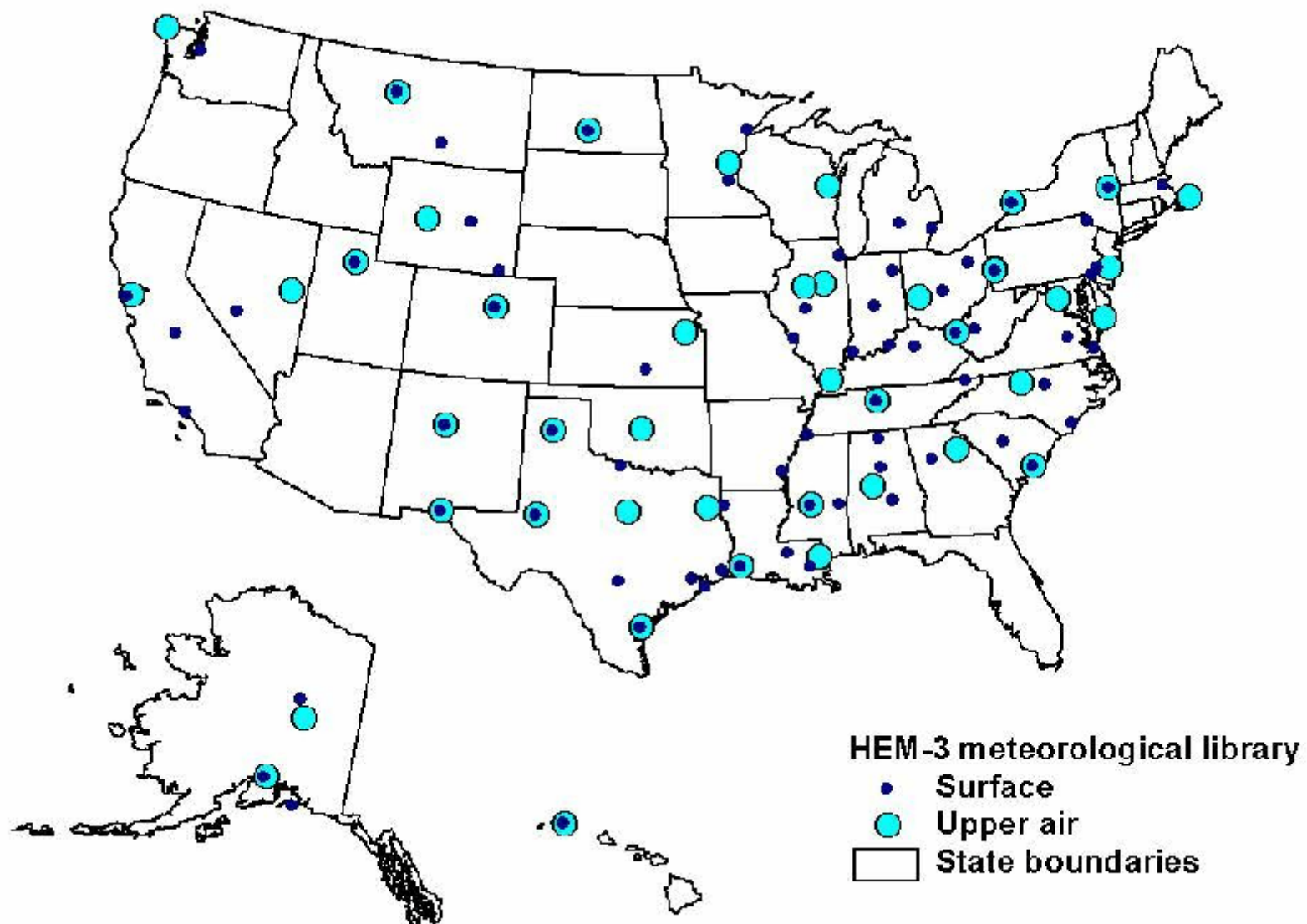


Figure 2. Meteorological Data Included with HEM-3.

Two preprocessor programs were used to produce meteorological files suitable for ISCST3. First, the Mixing Heights preprocessor was used to compute twice daily mixing heights from hourly surface observations and twice daily upper air soundings ([EPA, 1998b](#)). The PCRAMMET preprocessor was then used to calculate hourly values for atmospheric stability, to interpolate twice daily mixing heights to hourly values, and to calculate the parameters for dry and wet deposition processes ([EPA, 1999](#)). In addition to meteorological observations, PCRAMMET requires a number of properties representative of the meteorology site. These include: minimum Monin-Obukhov length, anemometer height, surface roughness length, noontime albedo, Bowen ratio, anthropogenic heat flux, and net radiation fraction absorbed by the ground. These properties were set using guidance provided in the PCRAMMET User's Guide. The output from PCRAMMET model becomes the input for meteorological data into ISCST3.

In some cases, the meteorological observation input files do not have values reported for every hour. Because ISCST3 requires that there be no missing values in certain required data fields, the missing data in those fields were filled using interpolation. However, if more than five consecutive required variables are missing, the year of data containing those missing variables cannot be used. In addition, if there is 10% or more of a required variable missing from one year of data, that year of data cannot be used. In general HEM-3 includes used the most recent data available, but in those cases, earlier years of data were used. In cases where there were not five years of good data available, another station was chosen for either the upper air data, the surface data, or both.

7. References

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